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OUTLINE OF CENOZOIC HISTORY OF A PORTION OF THE MIDDLE ATLANTIC SLOPE.[1]

In the spring of 1891, I published a preliminary account of the Mesozoic and Cenozoic formations of eastern Virginia and Maryland, in which there was given a brief resumé of the history.[2] Studies have been continued in the region, and much new information has been acquired, especially regarding the relations and history of the younger formations. Notice of the results of these studies was given at the meetings of the Geological Society of America, in December, 1892, and August, 1893. In this paper, there is presented a brief summary of the principal features, but further details and a more extended discussion, will appear later in a memoir now in course of preparation.

The middle Atlantic slope extends with fairly regular declivity from the Appalachian range to the ocean. It comprises two provinces, the Piedmont and the Coastal plain. The former, which lies to the westward, is a high undulating plateau carved in greater part in crystalline rocks; the latter slopes to the ocean, and is underlain by unconsolidated deposits ranging from Cretaceous to Pleistocene in age. The Piedmont belt is traversed by rivers which flow in gorges, and the minor water ways run in deep rocky valleys. The slope to the eastward is gentle and the province merges into the Coastal plain in a zone of moderate width, in which, to the northward, there is increased declivity. The surface of the Coastal plain comprises wide areas of plateau to the southward and rolling hills to the northward, which attain maximum elevations from two hundred to three hundred feet. It is bordered on the eastward by low terrace plains, and traversed by wide depressions, which contain terraces of various heights. The gorges of the rivers of the Piedmont belt open into these depressions and the larger rivers become tide water estuaries in the Coastal plain.

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[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Geol. Soc. Am., Bull., Vol. II., pp. 431–451; Plate 10.

The formations underlying the Coastal plain province are a series of widely extended sheets of gravels, sands, clays, and marls lying on an east-sloping floor of crystalline rocks. They are separated by unconformities and, in greater part, dip gently and thicken gradually, to the eastward. They emerge at the surface in succession to the westward, but there is more or less overlap of the younger formations beyond the edges of the older formations. The Cretaceous and Tertiary representatives are the Potomac and Raritan formations, consisting of clays and sands of early Cretaceous age; Magothy[1] sands and brown sandstones of Maryland; the great greensand series of New Jersey represented by the carbonaceous sands of the Severn formation in Maryland; Pamunkey formation consisting of glauconitic sands and marls of Eocene age; Chesapeake formation consisting of clays, fine sands, and diatomaceous clays of Miocene age, and the Lafayette formation consisting of gravels, sands, and loams of later Neocene or Pliocene (?) age.

On the terraces in the depressions, and on the low lands to the eastward, there are deposits of gravels, loams, and sands of Pleistocene age which have, in greater part, hitherto been comprised in the "Columbia formation." I have found, however, that these depositions consist of two series of deposits, an earlier, which lies on the higher terraces westward and is the basal member eastward, and a later deposit, which lies on the lower terraces, and overlies the earlier deposits eastward and southward of the Potomac valley. This difference in altitude is due to emergence and strong tilting from the northwestward between the time of deposition of the earlier and later deposits. The area of this emergence is shown by the heavier ruling in figure 4. The earlier deposit has not been differentiated before, but it is an important and distinct member of the Coastal plain series. The general relations of the various formations near the latitude of Washington are shown in the fifth section on figure 3.

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[1] Recently defined by DARTON, Am. Jour. Sci., 3d Ser., Vol. XLV., 1893, 45 pp.

TERTIARY BASE-LEVELS.

It is now very clearly recognized that the Piedmont plateau is a peneplain of Tertiary age. This plain extends eastward over the Coastal plain region, and with gradually decreasing altitude finally passes beneath tide water level not far from the present coast line. In the Piedmont region, the plain has been deeply trenched by drainage ways, but wide areas are preserved in the divides. On the Coastal plain, it is overlain by the Lafayette formation by which it is largely preserved to the southward, but in northern Maryland, Delaware, and New Jersey, this formation has been removed and the peneplain gives place to rounded hills or to later terrace levels. The Tertiary peneplain extends over the Piedmont plateau to the foot of the mountains and through their gorges into the great Appalachian valley. Its altitude near the Blue Ridge west of Washington is about 600 feet, but it rises gradually along the foot of this range to 900 feet on James river. A short distance west of Washington, its altitude is 400 feet, and a few miles to the eastward, where it is widely overlain by the Lafayette formation, it is 270 feet. At the shore of Chesapeake Bay, east of Washington, it is 110 feet, and near the mouth of the Potomac river, 90 feet. At Richmond, it is 200 feet, and it passes beneath tide level near Norfolk. These altitudes indicate a gradual slope to the east, and to the south along the Blue Ridge near James river. There is, also, a general increase of altitude to the northward along the Coastal plain, which has resulted in the wide removal of the Lafayette formation and degrading of the underlying peneplain in that direction. In figure 5, an attempt has been made to represent the contour of the peneplain by one hundred foot contours, restoring the portions which have been degraded. The steep slopes in the Washington-Baltimore region are due mainly to the inter-Columbia tilting. A portion of the general tilt to the east, especially to the southward, was probably pre-Lafayette, and the peneplain had originally, of course, a moderate seaward slope. The surface contour of the peneplain is quite smooth. On the

Coastal plain, the Lafayette formation lies on a very smooth surface, but there are low depressions along the lines of the present valleys of the larger streams south of, but not including, the Potomac. In the Piedmont region, there is a system of very low flat divides coincident with those of the present drainage systems. There are a number of "monadnocks" or unreduced areas of hard rocks, which rise more or less abruptly to various heights above the plain. These are shown on figure 5. Parrs Ridge, the large, unreduced area west of Baltimore, rises gradually to only a moderate elevation, but its slopes are nearly everywhere clearly demarked from the peneplain. The monadnocks are portions of the old Cretaceous peneplain which was the slope on which the Tertiary peneplain was excavated. Probably the tops of some of the higher monadnocks stood above the Cretaceous plain.

During the development of the Tertiary peneplain, there were deposited the Chesapeake, Pamunkey, and possibly portions of earlier deposits, and the long time intervals by which these formations are separated represent intervals of uplift and increased planation. It has not been possible, as yet, to differentiate the topographic products of these epochs in the Piedmont region, and probably the local features to which the earlier conditions gave rise were effaced in succeeding epochs. A certain amount of base-levelling progressed in the Piedmont region during the deposition of Lafayette formation, but the relative amount is not known. Probably it was not great for the formation represents but a small time compared with preceding depositions and uplifts.

TERTIARY DEPOSITS.

There are three formations of Tertiary age in the Coastal plain region, Pamunkey (Eocene), Chesapeake (Miocene), and Lafayette (Pliocene?). The Pamunkey formation consists of glauconitic sands and marls, which attain a thickness of about 180 feet east of Washington. It represents but a small proportion of Eocene time, and according to a recent comparison by G. D.

Harris,[1] is equivalent to a small member near the lower portion of the Eocene series of the Gulf region.

The Chesapeake formation consists of clays and fine sands with large amounts of diatom remains in the lower members. Its thickness is about 800 feet in eastern Maryland and Virginia, but it is only from fifteen to thirty feet thick about Washington, and is thin all along its western edge. In New Jersey, it is over 1,400 feet thick in artesian wells at Atlantic City, but here it includes a lower series, the Shiloh marls, which do not reach the surface in Maryland and Virginia. In the Gulf region, there are still older Miocene members. The youngest members so far studied are found in the Yorkton-Suffolk region, in Virginia, and these are at about the horizon of the youngest Miocene known.

The Lafayette formation consists of bowlders, gravels, and sands westward, but the materials become finer to the eastward and southward. It is a thin sheet varying from fifteen to twenty feet in thickness in greater part. It overlaps the edges of preceding formations, and its western edge extends for some distance on the crystalline rocks in the Piedmont plateau. A shore formation of talus and bowlders along the eastern foot of the Catoctin Range is of this age, and according to Mr. Keith there are outliers on a high summit a short distance eastward.

As before mentioned these formations are the products of the base-levelling of the Piedmont region. They are separated by erosion intervals, during which base-levelling extended over the Coastal plain region.

The western thinning of the Pamunkey and Chesapeake formations may be due entirely to increased uplift and planing in that direction, but there is some meagre stratigraphic evidence that the original deposits thickened eastward, and that there are older members in that direction which are overlapped westward by the later deposits of the formations. Throughout its course, the Pamunkey formation is overlapped westward by the Chesapeake formation, although at a few localities, the overlying Chesapeake beds have been removed locally. The original extent westward of the Chesapeake and Pamunkey formations is not known, for no shores or shore deposits remain, and the superimposed drainage may be of later age. As they were deposited in moderately deep waters and the shores were probably low, at least in Chesapeake times, it is possible that the deposits may have originally extended far west of their present terminations. In Virginia, both formations abut against steep shores of crystalline rocks or Potomac sands, but in their original thickness they may have overlapped these local steep shores. About Washington, and west of Baltimore, outliers of probable Chesapeake cap the highest summits under a protecting cap of Lafayette gravels, and as one stands on these outliers and looks westward, there is strong suggestion that the formations may have originally extended far in that direction.

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[1] Am. Jour. Sci., 3d Ser., Vol. XLVII., April, 1894, pp. 301-304.

PLEISTOCENE TERRACES.

The earlier Pleistocene terrace, or that on which the earlier Columbia deposits lie, is tilted to a high altitude to the northwestward, but it dips to the east and south, and finally passes beneath the terrace level of the later Columbia deposits. The latter is also slightly tilted to the eastward. As the southeastward tilt of the Tertiary peneplain is greater than that of the Baltimore terrace, the Lafayette formation passes beneath the deposits of that terrace along a line near the zero line in figure 5. The relative slopes of these terrace levels and the Tertiary peneplain near the latitude of Washington are shown in the following diagram:

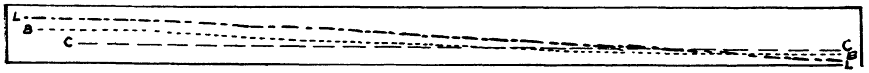

Figure 1. Diagram of earlier and later Columbia terrace plains and Tertiary peneplain near the Latitude of Washington. Vertical scale greatly exaggerated.

In the vicinity of Washington, where the relations are particularly well exhibited, the earlier Columbia terrace has an altitude from 215 to 180 feet, with the Lafayette formation on the Tertiary peneplain about 100 feet above. The later Columbian terraces are in a series, of which the highest averages about 100 feet in altitude. Both are separated by steep bare scarps, which are continuous for long distances. Florida, or Boundary Avenue, is at the foot of the younger scarp for several miles, and this scarp is a marked feature all about the Washington amphitheatre. The earlier Columbia terrace extends widely around Washington, and far up the Potomac valley, at first with rapidly increasing elevation. It is clearly exhibited in the Frederick valley at an altitude of 400 feet, and Mr. Keith has called my attention to extensive terracings in the Goose Creek valley and extending across to the head waters of the Occoquan, which are of earlier Columbia and Inter-Columbia age. In descending the Potomac, the altitudes of the earlier Columbia terrace are found to gradually decrease, and finally it passes beneath the later Columbia terrace and deposits, about thirty miles below Washington.

In the Baltimore region, the relations are very similar to those in the Potomac valley. The upper part of Baltimore is built mainly on the earlier Columbia terrace at altitudes from 140 to 200 feet. The terrace and its deposits have been found to extend up the Jones Falls depression to an altitude of 380 feet in eleven miles, and there are similar relations in the Gunpowder valley, where the same altitude is finally attained. This is a much steeper slope than exists in the Washington region, and the tilting here attains its maximum degree. Between Washington and Baltimore, there is a moderately wide depression, which holds areas of various sizes of early Columbia terrace at altitudes from 180 to 240 feet. This depression expands widely in the region between the Patuxent and the Patapsco, and towards the bay the altitudes gradually decrease to sixty feet near the bay shore. On the eastern shore of Chesapeake Bay, the deposits of the early Columbia terrace are overlain by the later Columbia deposits at an altitude from five to twenty-five feet above tide water, and to the eastward there is only a very gentle slope seaward. In the region south of the lower Potomac, the relations are similar to those east of the bay.

The later Columbia terraces extend in a wide belt along the ocean, covering all of the eastern shore of Maryland and Virginia, and extending up the tidal estuaries to and into the Piedmont region. They pass below tide level along the coast line and extend far out the submarine slope. To the westward, they gradually rise to from 60 to 100 feet in the depressions near the western margin of the Coastal Plain province. They extend up the Piedmont gorges for some distance, but are, of course, there greatly narrowed. Along the north side of the Potomac gorge above Washington, there is a narrow discontinuous shelf which gradually rises to 145 feet at Great Falls, where it becomes the floor of the valley. The inner gorge below the Falls has been cut through the later Columbia terrace. The later Columbia terrace extends up all the small valleys along the Coastal Plain, but is often considerably degraded in them.

PLEISTOCENE DEPOSITS.

The Pleistocene deposits consist of gravels, loams, and sands. In the typical development, there is a basal member containing gravels and bowlders, which merges upward into loams. On the earlier terraces, there is a formation of this character, which for the present may be designated "earlier Columbia." On the later terraces, there is a similar deposit which has long been known as the Columbia formation, and this for the present shall be differentiated as "later Columbia."

In the region to the west and north of Washington, where the earlier terrace is highly elevated, the earlier Columbia is at high altitudes, and the later Columbia deposits lie on the low terraces in the deeper portion of the depressions, but to the east and south, the later Columbia lies in regular succession on the earlier Columbia deposits. The evidences of the separateness of these two formations westward are the bare scarp of erosion intervening between the terraces, and, in a measure, the difference in degree of inclination. In some districts there are wide areas of bare slopes between the upper and lower terrace levels. In portions of the region eastward, a series of cross-bedded sands has been found to intervene between the earlier and later

Columbia deposits, which represents the products of the subærial erosion of the inter Columbia uplift in the region westward. In his report on the "Geology of the Head of Chesapeake Bay,"[1] McGee describes several exposures of this feature and represents it in his general section, but gives no suggestion as to its interpretation. It has been found to be general over a wide area, but is not everywhere equally distinct. The relations are shown in the following figure:

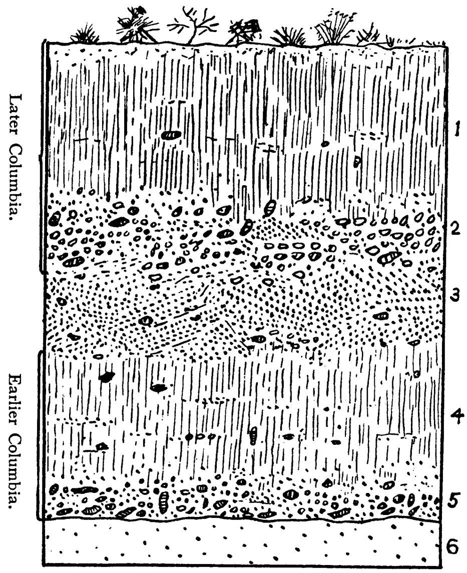

Figure 2. General section of Pleistocene deposits on the eastern side of Chesapeake Bay showing relations of cross-bedded sands between the earlier and later Columbia deposits. 1. Loam. 2. Gravel and bowlder bed. 3. Cross-bedded coarse sands. 4. Loam, with scattered pebbles, etc. 5. Gravel and bowlder bed. 6. Pre-Pleistocene formation.

The basal beds of each of the Pleistocene formations contain very coarse material to the westward which comprise bowlders, pebbles and sub-angular masses of quartzite, quartz, crystalline rocks, sandstones, and cherts, more or less closely packed in sands and loams. Some of the masses stand on end, and these strongly suggest that they were carried by ice and dropped in their present attitudes. The loams contain scattered pebbles and bowlders, and pebbly and sandy streaks. Locally the formations consist entirely of pebbly sands. To the eastward, there is a gradual decrease in the coarseness of the materials. These statements apply about equally to the earlier and later Columbia deposits, but, on the whole, the materials of the earlier Columbia are often coarser than those of the later Columbia. Both formations contain local streaks of ferruginous conglomerate, but the earlier Columbia deposit presents much of this material, and east of Washington it is a conspicuous feature. In some portions of the regions between the valleys of the Potomac and Patuxent, and northeast of Baltimore, the earlier Columbia formation becomes very thin, and consists largely of local materials. The thickness of the later and earlier Columbia deposit averages twenty feet each.

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[1] U. S. G. S., 7th Ann. Rept., 1888. Pp. 537–646. Plates.

The earlier Columbia deposit has been widely removed from the higher altitudes, and up the Piedmont gorges is represented by meagre fragments. The widest areas now constituting the surface are southeast of Baltimore, and south of Washington, west of the Potomac. In the upper part of Baltimore, and about Mount Pleasant, the upper part of Washington, there are moderately large areas. In the valleys north of Baltimore there are many thin patches of earlier Columbia gravels, and some of these widen considerably in the limestone valley of the Cockyville region. In the Rock creek valley, near Washington, there are many small areas of the deposits at from 195 feet to 205 feet, and an early Columbia delta at the broad intersection of the 200-foot terrace level with the gorge above.

The later Columbia deposit is not widely degraded, and it has only been removed over the area occupied by tide water, and narrowly trenched by the various small water ways.

POST-COLUMBIA RELATIONS.

The principal Post-Columbia features are the channels which have been cut through the Columbia terraces, recent alluvium, wash on slopes, and marsh. The Post-Columbia channels are in greater part flooded by tide water, which, to the southeastward, extends to slightly above the base of the Columbia formation. These channels have a depth of 150 feet in the deepest portion of Chesapeake Bay, but decrease in amount to the westward. They are excavated *through* the Columbia deposits and are not floored by that formation, as suggested by McGee. Throughout the region, the later Columbia deposit caps cliffs at the waters edge, and to the northward its base is usually considerably above tide water and various subterranes appear below. Many of these cliffs have been cut back more or less by lateral wave action, but there are numerous others which are due entirely to vertical erosion. All the tide water channels are cut deeply into formations underlying the Columbia deposits, and the base of the very lowest Columbia deposits southward is but a short distance below low tide. Several years ago I obtained a sample of the bottom of the Chesapeake bay in twenty feet of water, a mile from the west side of the lower bay, and it was typical Chesapeake clay containing a perfect, very fragile shell of a characteristic *tellina*. At Claiborne, on the east side of the bay, extensive dredgings were made for a long railroad dock, and the lower diatomaceous clays of the Chesapeake formation were found to be practically bare in the bottom. In Patapsco river, the dredgings out of the channel brought up typical Potomac clay at twenty-seven feet, which was overlain by a few feet of river mud. McGee[1] states that the boring on Spesutic island, near the head of the bay, was through 140 feet of sands and silts, which were thought to be neither Columbia nor Potomac. I believe, however, that in the lower portion of this well some Potomac sands may have been penetrated. The well, however, proves the existence of a deep channel here with a great mass of alluvial filling.

Owing to submergence now in progress, alluvial deposits are mainly laid down in tide water. In the Piedmont region, and in some of the smaller valleys, there are transient accumulations of alluvium on freshet planes. Throughout the region, there are overwash deposits, or talus, on slopes and in some small depressions. Marsh growth keeps pace with subsidence in many regions, and there are numerous large marsh areas along the principal tidal estuaries.

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[1] Loc. cit.

There are recent dune sands on the coast and older dunes inland in part of the eastern shore region, but I have given no special attention to their relations.

RESUME OF HISTORY.

The earliest event in the Tertiary history of which there is evidence was the deposition of the Pamunkey formation in Eocene times Its fine, glauconitic, highly fossiliferous sands were evidently deposited in moderately deep waters containing an abundant fauna. The extent of the maximum submergence by Pamunkey seas and the original extent and thickness of the formation are not known. As the formation represents but a small proportion of the total Eocene known in other regions, there either were long intervals in which this region was a land surface (and this was undoubtedly the case during the deposition of older Eocene formations elsewhere) or overlying formations, if deposited, were subsequently removed. Consequently the erosion interval between the Pamunkey and Chesapeake formations may have been inaugurated soon after the end of Pamunkey deposition, or it may have followed much more extensive deposition of later Eocene formations which were removed before Chesapeake deposition. It is ascertained that the entire present Coastal Plain region emerged before Chesapeake deposition and there was general planing or base-levelling, but the extent of uplift, the amount of tilting, and the depth of degradation which followed are not known. Some light may be thrown on these questions when the stratigraphy of the Pamunkey formation is more accurately determined. The emergence was followed by submergence during which the Chesapeake formation was deposited. As these deposits have a known thickness of 800 feet to the southeastward, and over 1,400 feet in New Jersey, and consist of very fine-grained materials, and are in part diatomaceous, their deposition occupied a very long period of deep submergence; but how deep and how wide-spread are not known. The western edge of the Pamunkey formation was widely overlapped, and it is probable that the older Miocene formations were also overlapped far to the eastward. The conditions of erosion and sedimentation differed considerably from those of Pamunkey times, for the fine sands and clays, diatomaceous in part, have had a different history from the glauconitic sands and marls of the Pamunkey formation. The uppermost members of the formation, which are found in the southeastern corner of Virginia, were laid down during the uplift of the Chesapeake formation, for the mingled sands and shell fragments indicate proximity to a shore. They are very young Miocene and contain a large number of Pliocene shells. This emergence was probably part of the general uplift and planing which followed Chesapeake deposition. It was a general base-levelling precisely similar to that of the Post-Pamunkey emergence, and there are similar limitations to our knowledge of the extent of uplift, amount of tilting, and depth of denudation. In both uplifts there was slight tilting from the westward. It was during Pamunkey and Chesapeake times that much of the base-levelling of the Piedmont region was effected, but if these formations were originally spread far westward over the surface of the crystalline rocks, their presence retarded the base-levelling for the time being.

Following Post-Chesapeake erosion there came a moderate amount of submergence and the deposition of the Lafayette formation. Another change had taken place in the conditions of erosion and sedimentation, for coarse sands and gravels were spread about by waves and currents over a wide zone in the vicinity of the shore. Farther eastward there were deeper waters and the sands and finer materials were deposited in them. How far west the waters spread is not known, but the shore deposits along the base of Catoctin Mountain indicate general submergence of the peneplain for at least a portion of the time. The great sheet of typical sediments was apparently not spread far beyond its present limits on the divides, but it widely overlapped the edge of the Chesapeake formation and many outliers of Potomac formation. It was from the lower and marginal beds of the Potomac formation that much of its material was derived.

Lafayette deposition was followed by relatively rapid uplift, during which there were carved the wide steep-sided troughs of the river valleys and a wide shelf along the coast to the east and north. It was at this time that the present topography of the Coastal Plain region was outlined for, in previous emergences, there had been only a general planing. It is thought that the irregular course of the rivers across the Coastal Plain, notably the southerly deflections of portions of the Delaware and Potomac rivers and the head of Chesapeake Bay and the local drainage relations, were due to the original contour of the surface of the Lafayette deposits. This surface had a peninsular configuration similar to the submarine sand bars now existent along the ocean coast, and, with uplift, the "sloughs" determined the location of the water ways. The deflected courses of the rivers are not related to any orogenic influence so far discovered, as suggested by McGee, nor to the texture of the deposits they traverse. Post-Lafayette emergence was greatest in amount to the northward, and in northern Maryland, Delaware, and New Jersey, the formation was widely eroded, together with the underlying formations. All of this region was planed to a terrace level, and a wide depression was excavated along the western margin of the Coastal Plain region from Baltimore to Washington. Wide valleys and series of terrace plains were cut in the Piedmont region, especially in the areas of softer rocks in the Jura-Trias and limestone valleys adjoining the Susquehanna and Potomac depressions.

In figure 3 there are given a series of sections which illustrate the conditions at a number of periods following the Lafayette uplift.

In the second section in this figure is shown the relative amount of the erosion during the uplift following Lafayette deposition, along a line passing near the latitude of Washington.

To the northward the degradation extends farther and farther westward, and finally covered the entire width of the Coastal Plain. To the southward its amount diminishes gradually.

The next epoch was one of general subsidence by which the terrace plains of the last epoch were submerged to a moderate depth, and the earlier Columbia was deposited. The extent of this submergence is represented in the following figure, and some of its relations are shown in the second section in figure 3.

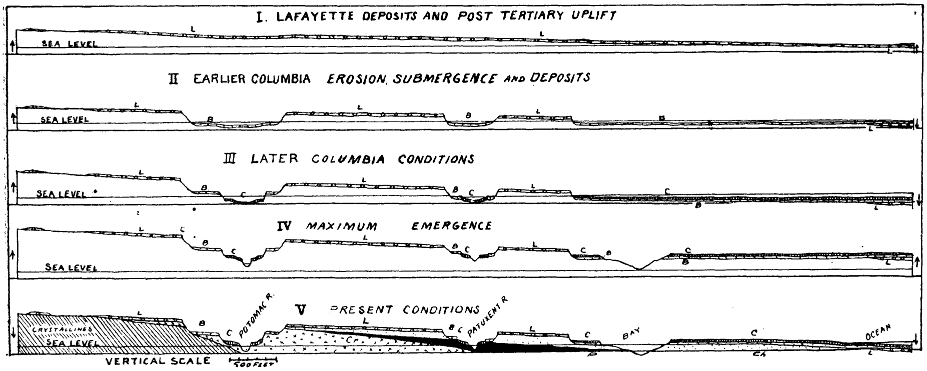
I. LAFAYETTE DEPOSITS AND POST TERTIARY UPLIFT
SEA LEVEL
L
II EARLIER COLUMBIA EROSION, SUBMERGENCE AND DEPOSITS
B
III LATER COLUMBIA CONDITIONS
C
IV MAXIMUM EMERGENCE
V PRESENT CONDITIONS
CRYSTALLINES
POTOMAC R.
PATUXENT R
Cr.
BAY
OCEAN
VERTICAL SCALE
500 FEET

Figure 3. Sections near the latitude of Washington to illustrate the Post-Tertiary history of the Coastal Plain region. L. Lafayette formation. B. Earlier Columbia deposit. C. Later Columbia deposit.

In the earliest stage of earlier Columbia submergence, a heterogeneous mass of coarse material was deposited, but with increased depth of water the fine loams and sands were laid down. The coarsest materials were deposited near shore, and in the course of the estuarine channels of the rivers. Further off shore there were finer deposits, and out of the river currents, there was less deposition, and the deposits consist in larger part of local materials. This period is correlated with the first ice invasion of the glacial epoch.

Following the earlier Columbia deposition the general Post-Tertiary emergence continued to the northwestward, but to the south and east there was either no movement, or slightly increased submergence. The uplift northward was such that the area shown by the heavy rulings in Fig. 4 emerged, finally, to

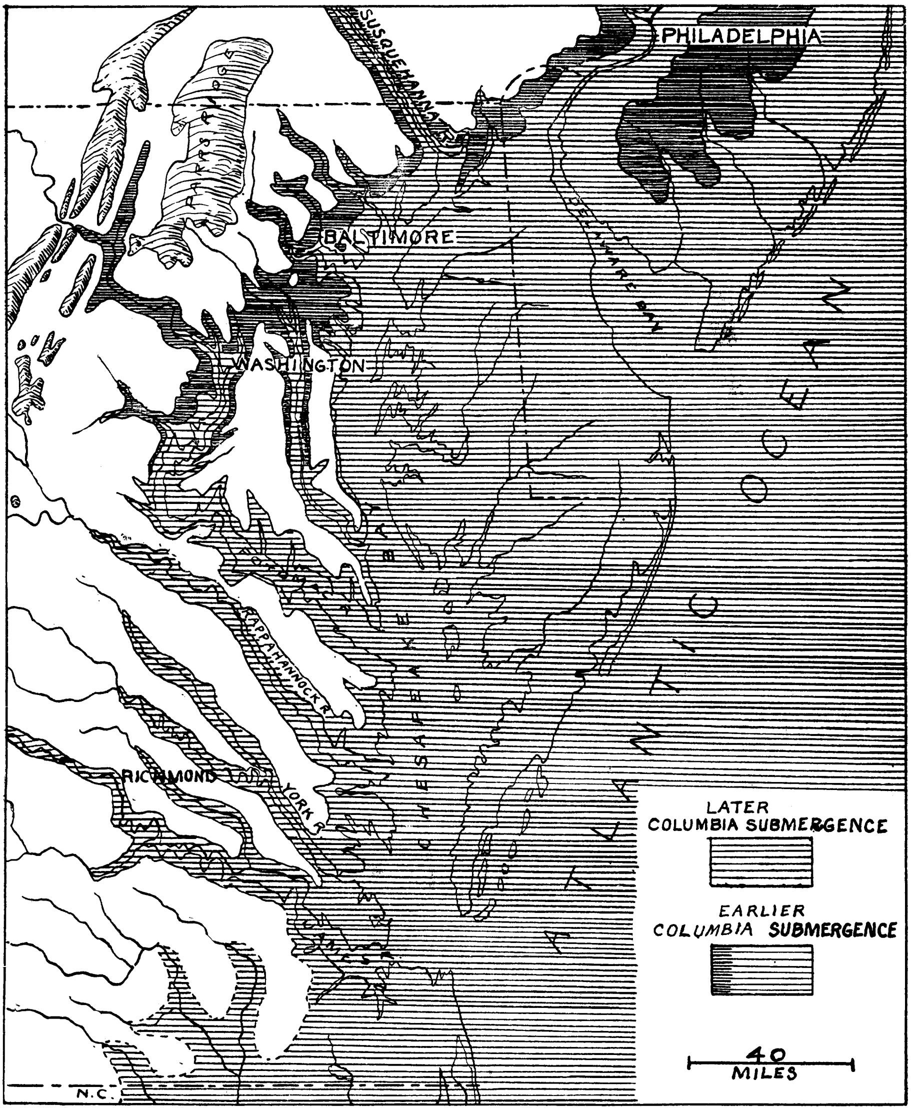

Figure 4. Map of the Middle Atlantic region to illustrate the extent of the Pleistocene submergence.

about 150 feet above the water in the portions westward. The streams in this region were revived and a terraced trough was cut within the earlier Columbia trough. That this uplift was also rapid is indicated by the steep sides of the trough, but the emergence was not so long continued as the Post-Tertiary uplift, for when base-level was reached the trough was widened only about half as far. The general nature of this trough in the Washington region and eastward is shown in the third section in figure 3. Farther northward the earlier Columbia terrace was more widely degraded, owing to the somewhat increased amount of uplift in that direction. During this epoch there was considerable erosion in the Piedmont region, shown mainly in the cutting of steep-sided inner gorges, and a general deepening of the drainage ways. As the cutting reached base level a series of wide terraces were cut in the vicinity of Washington, along the Delaware valley and around southern New Jersey, which were essentially continuous with those of the submerged region to the east and south. During the uplift this submerged region received the products of the degradation, and the coarse, cross-bedded sands, shown at 3 in figure 3, are just what we should expect under the conditions.

The widening of the Inter-Columbia troughs was terminated by general subsidence, during which the later Columbia deposits were lain down under conditions almost precisely similar to those of the earlier Columbia deposition; first, the coarse basal beds, and then the fine loams, with few scattered bowlders and fragments. They were deposited on the lower terrace plains of the depressions in the uplifted region, but to the eastward they were laid down in open waters.over the earlier Columbia deposits and the intermediate deposit; 3 in figure 3. The later Columbia waters extended across the Coastal Plain region in the larger valleys and for some distance into the Piedmont region, but their western limits are not definitely known. In figure 4 the area of later Columbia submergence is represented, and some of its relations are shown in section 3, figure 3. The later Columbia terraces extend to the Great Falls in the Potomac, but the later Columbia waters do not appear to have extended beyond the Falls.

In the James river valley the Pleistocene submergence was continuous below Richmond. Either the earlier Columbia or later Columbia waters, or the continuous Pleistocene submergence may have extended far westward. Mr. Keith informs me that there is a succession of gravel-capped terraces along the valley in the Lynchburg region, and these may represent Lafayette, earlier Columbia, and later Columbia deposits, laid down in succession during oscillations in a general uplift, as in the

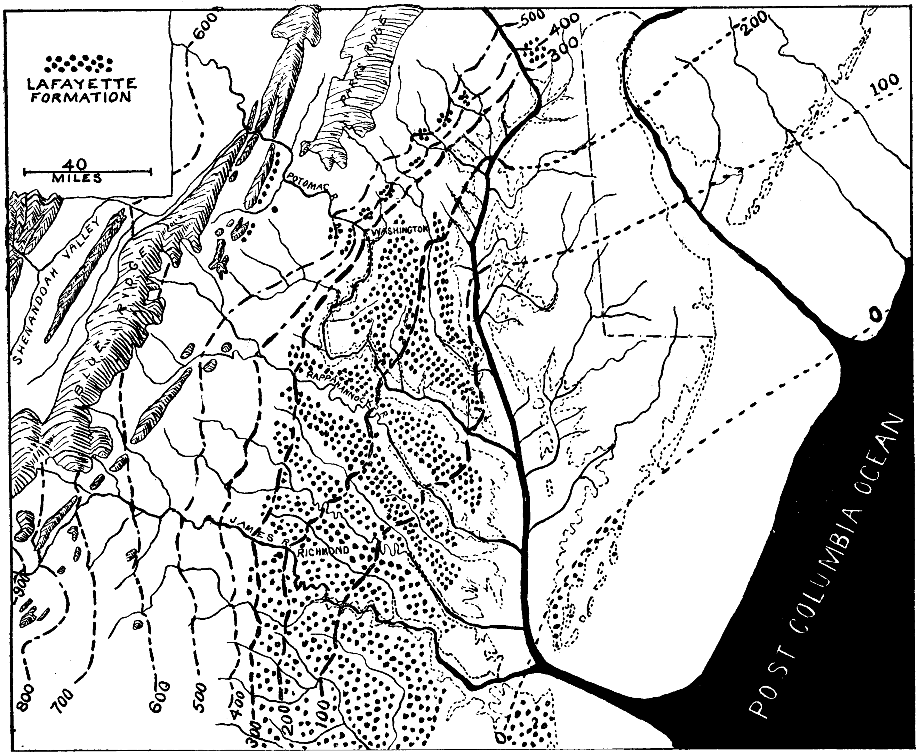

Figure 5. Map of the Middle Atlantic Slope, indicating the conditions in the time of Post-Columbia maximum uplift. There is also shown on the map the nature of the deformation of the Tertiary peneplain in 100 foot contours; and the present extent of Lafayette deposits.

Washington and Baltimore region. The age of the high tilting of the Tertiary peneplain in the James river region in the Piedmont province has not been determined, and a study of these gravel terraces should throw much light on its history.

Following later Columbia deposition the uplift continued, but without much tilting. The entire Coastal Plain region was finally lifted from 100 to 150 feet above tide water, and deep channels cut through the later Columbia terraces. The drainage conditions at this stage are represented in figure 5 and in section 4, figure 3.

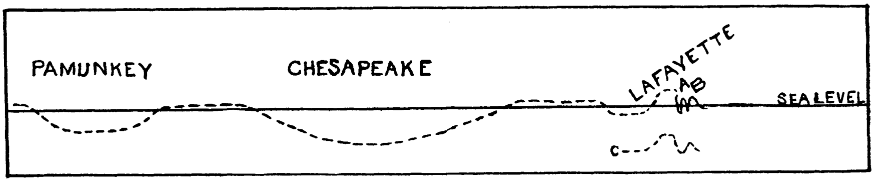

Figure 6. Diagram of Cenozoic oscillations of land and water in the Middle Atlantic Coastal Plain region. A. Earlier Columbia. B. Later Columbia, C. The conditions east and south of the area of inter-Columbia emergence.

This was the maximum degree of uplift, and was of short duration, for the valleys were not greatly widened, and they had a relatively steep inclination seaward. It was followed by subsidence, which is still in progress, and has resulted in the flooding by tide water of the larger Post-Columbia valleys of the Coastal Plain region. The total rate of this subsidence is not known, but on the coast of New Jersey its present rate has been estimated by Professor Cook at two feet per century. In many districts the incursion of tide water is kept pace with and even slightly exceeded by the deposition of silt and other detritus. These accumulations, in themselves, indicate subsidence, for the deposition is mainly due to slackening of currents in the shallower channels, due to tide-water incursion. Marsh growth keeps pace with subsidence in many portions of the region.

In the following diagram an attempt has been made to represent the nature of the oscillations of the Coastal Plain region, but, owing to the meagerness of quantitative data, is not very satisfactory.

Certain general relations in this diagram are founded on definite data. They are the relatively greater length of Chesapeake submergence, the shortness of Lafayette definition, and the relatively short submergence of Pleistocene times. The Post-Lafayette emergence is shown to be greater in vertical amount than the earlier emergences, by the sub-aerial trough-cutting which ensued, but there may have been similar or deeper gorges in earlier times, which were finally effaced by base-levelling. That the Inter-Columbia uplift was of shorter duration than the Post-Lafayette is indicated by the relative narrowness of the inner trough.

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